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Navigation and motion control techniques for surface unmanned vehicle and autonomous ground vehicle: a review

Putri Nur Farhanah Mohd Shamsuddin[1], Roshahliza M. Ramli[2], Muhamad Arifpin Mansor[3]

[1,3]Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, Malaysia
[2]Faculty of Electrical and Electronic Engineering Technology, Universiti Malaysia Pahang, Malaysia

Article Info

ABSTRACT

An excellent navigation, guidance, and control (NGC) system had a high impact on trajectory tracking and the following scenarios. Both scenarios will include the heading, tangent, and velocity parameters in the computation. However, the control system design problem is not a new issue in the unmanned surface vehicle (USV) and autonomous ground vehivle (AGV) due to this constraint faced by many researchers since early these autonomy developments. Hence, this paper listed and emphasizing the techniques, including techniques implementation, strength, and the algorithm's constraints, a fusion of several techniques implemented for vehicle's stability, a turning ahead, and heading estimation. This paper concerns the similar algorithm used in the USV and AGV. Most of the selected techniques are basic algorithms and have been frequently implemented to control both vehicles' systems. Previous research shows pure pursuit guidance is the most popular technique in AGV to control the degree-of-freedom (DOF) velocity and the dynamic rate (sway, surge, and yaw). Simultaneously, the line of sight (LOS) controller is very compatible with controlling the movement of the USV. In conclusion, the technique's simulation test needs further research that will expose in the actual situation.

Corresponding Author:

Roshahliza M. Ramli
Faculty of Electrical and Electronic Engineering Technology
College of Engineering Technology
Universiti Malaysia Pahang
26600, Pekan, Malaysia
Email: roshahliza@ump.edu.my

1. INTRODUCTION

An autonomous vehicle is an advanced mechanism that operates without human intervention and decreases its risk from performing the mission. Based on the previous research, many unmanned surface vehicle (USV) and autonomous ground vehicle (AGV) performed longer in hazardous situations, such as; military identification, home protection, low-water surveys, and environmental surveillance [1]. Hence, autonomous vehicles' employment, which is consistently exposed to the risk situation, needs improvement in sensing, communication, and computing technologies. The USV and AGV consist of four types of mechanism which depends about the mission. For example, AGV are used for operation on the land, USV for water mission, unmanned underwater vehicle (UUV) for underwater surveillance, and unmanned aerial vehicle (UAV) for air operation. All these mechanisms communicate with the operator for several systems and link them together to perform the task. For example, UUV was built a relay interaction network on the water to develop wireless communication with the USV [2], [3]. In 2017, the latter was deployed in USV that built the communication with the REMUS100 AUV by using an automated method that involved movement

between them [4]. This paper concerning two types of vehicles, USV and AGV, explores these vehicles' performance based on similar techniques implemented in the control system and how their performances are based on the techniques.

Several primary automation vehicles have researched smart USV and AGV and made technological progress in producing them [5]. An automated vehicle system's autonomy generally has differed into six levels, as defined in SAE-J3016 [6]. Besides, listed that six components were divided into the USV and AGV's vital components: the onboard system comprising additional structural elements, propulsion power system embedded, data gathering equipment, navigation, and control systems (GCC), ground station, and the system of communication. Stated the onboard system complementarily entails the guidance, navigation, and control subsystem, which work in interaction with each other [7]. Besides, the NGC module requires onboard software installation instruction through the computer to manage the entire USV and AGV. The navigation system comprehensively assists USV and AGV in identifying the current and future pose between two positions that are examined based on sensing, state estimation, environment perception, and situation awareness. The standard navigational devices have been introduced, such as global positioning system (GPS), electronic compass, inertial measuring unit, and gyroscope. The additional module consisting of IMU and stereo camera was designed to increase the robustness to decide if other sensors operate.

The USV and AGV are ordinarily designed based on the sizeable power-to-weight proportion. Due to these properties, new motion control concepts that involve the motion and the speed of the USV and AGV are highly demanded in this area of autonomy. However, motion control is the biggest problem that occurred in USV and AGVs. Previous studies have reported that the control system design problem is not a new issue in the USV and AGV due to this constraint faced by many researchers since the early autonomy development by upgrading several techniques to enhance the motion control system. In 2010, Oh and Sun stated the excellent control system had a high impact on the trajectory tracking and the path following scenarios. Hence, the control community studies attracted many researchers to upgrade the onboard subsystem [7].

The vessel's movement will depend on its transfer function, which is defined and measured in the DOF state. The vessel's transfer function used the term response amplitude operator (RAO) collectively for associated the phase angles, which respect the movement of the USV's centre of gravity. A computation of AGV and USV displacements, acceleration, and velocity will be calculated by RAO and generally issued in the following format for each wave period and direction in Table 1.

Table 1. Vessel six degrees of freedom

Wave Period and Direction	Transfer Function	Phase Angle
Surge (m/m)	x	a_x
Sway (m/m)	y	a_y
Heave (m/m)	z	a_z
Roll (deg/m)	R	a_R
Pitch (deg/m)	P	a_P
Yaw (deg/m)	Y	a_Y

The guidance system generates optimal trajectory commands that are smooth and feasible to help USV and AGV move towards the next position. All the commands are continuously updated according to the information provided from other medium platforms such as vehicle capability and navigation systems. The navigation system defines current and potential AGV and USV through location, orientation, speed, and acceleration. Information about the surrounding environment was included when the USV and AGV current and past positions are determined [8]. This method needs to deploy several sensors to estimate the current situation. Generating a good control system to identify the appropriate control forces and moments will produce a navigation and guidance system that had built the same trajectory with the target. Several kinds of research discussed the USV motion control was designed theoretically based on the AGV [9]. The waypoint navigation and remote-control mode are interfaces in the USV motion control to enhance the functionality of this autonomy [10]. Increase USV performance for the high-exactness mission, which concentrates in shallow water by using traditional autopilot structure in the guiding controller of the AGV [11]. By adding a GPS in the autonomous onboard system, the conventional motion control technology can dignify the auto-speed, straight-line, and auto-heading towards the target position.

Figure 1 and Figure 2 show the AGV and USV vehicle's longitudinal (x), lateral (y), and vertical (z) axis based on the linear and rotational movement. Surge, sway, and the heave reckons as linear movement, while roll, pitch, and yaw are known as rotational movement. The vessel's movement will respect the surge, sway, heave, roll, pitch, and yaw, known as six degrees of freedom (DOF).
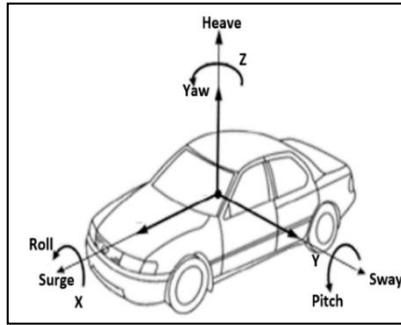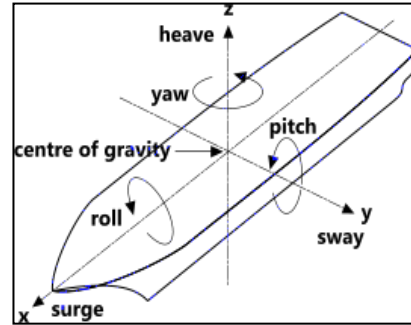
Figure 1. AGV's Six DOF

Figure 2. USV's Six DOF

The design of USV and AGV generates the reference curve for the path based on the time parameter called trajectory tracking. In-depth, Amer *et al*. [12] stated that this scenario refers to the AGV characterized by the motion's direction preferred by the control design. The control system focuses more on practical implementation on conserving the reference speed and reducing time limitations. For example, the constrained reinforcement learning concept helped decrease 84% waiting for the vehicles' time optimization and constant improvement of signal and trajectory for USV and AGV operation modules [13]. Nevertheless, this paper does not deal with neural network method studies.

A path-following algorithm is a crucial part of motion control by defining the distance, computing the trajectory path, and hitting the waypoint position by reducing the distance to zero. These scenarios will include the heading, tangent, and velocity parameter in the circumstance. For example, the mother vessel will follow the trajectory path design in the control system. Then, the controller will be generating the path that estimating the distance with the mother vessel.

Figure 3 shows the vehicle's kinematic equation describing the velocity in global coordinates, v_X, v_Y, and local coordinates, v_x, and v_y. The total velocity, v, and the vehicle's heading, θ, concern the local coordinates while the vehicle's orientation, ψ, is more intended on the global coordinates. Figure 4 shows the illustration of the USV position follows the trajectory path after estimate the heading error. The USV heading θ_d examines the waypoint position to identify the heading error based on both platforms. The turning radius, δ of the propellers, depends on the estimation radius, r on the cartesian plane. USV turns to the correct angle based on the USV displacement, v. Based on the figure, the dotted line refers to the USV platform's motion while the entire line refers to the current position of the USV. The USV movement is depending on the commands generated by the controller.
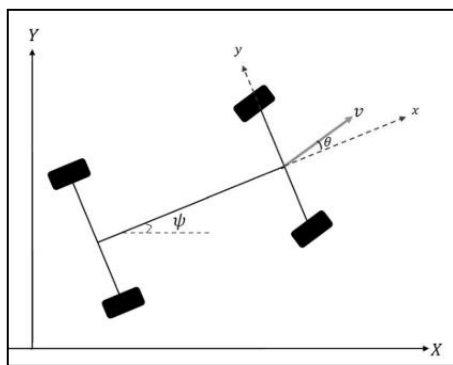

Figure 3. AGV in kinematic model towards desire heading [12]
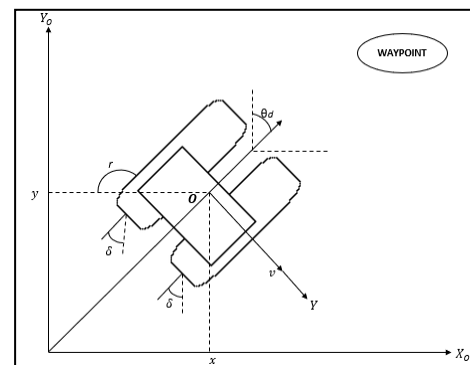
Figure 4. USV in kinematic model towards desire heading

In mechanical studies, kinematic is characterized as observing a body's motion without regard to its internal energy, forces, and inertia. Consequently, in terms of position, speed, and acceleration, the cinematic vehicle model can represent movement, regardless of internal dynamics. Modelling for kinematic vehicles can be used in most monitoring studies because of its simplicity and essential relationship to its motion. This

model is commonly used to describe the multiple vehicular velocity and acceleration in the lateral direction and the vehicle's yaw motion with local coordinates and global coordinates [13].

The path that is generally known as the waypoint is a series of discrete points generating a command by the controller to reach the next position. Target speed is used as a reference point to produce a waypoint represented by x, y, direction, and velocity to determine a two-dimensional space's location and direction. In 2003, Petrinec *et al*. [14] investigated the AGV and USV that move on the path, defined as a straight line between two waypoints. Designing a good control law will increase the performance of the USV and AGV. However, to reach a time parameterized, USV and AGV control law needs to follow the reference trajectory's motion, which, also known as the common problem, occurred in typical motion control. Trajectory tracking controller design is more accessible deployed in an actuated vehicle, but under-actuated controller design unable to fully feedback linearized due to the non-holonomic constraints was occurred [15].

Based on the review of several journals and conference papers, the author concerns the similar algorithm used in the USV and AGV. Most of the selected techniques are basic algorithms and have been frequently implemented to control both vehicles' systems. The techniques selected are based on the prevalent method implemented in the autonomous vehicle's control system since 2010, which included: pure pursuit (PP) guidance, line of sight (LOS) guidance, constant bearing (CB) guidance, Lyapunov-based guidance, kalman filtering, backstepping method, predictive trajectory planning, and motion goal prediction.

2. TECHNIQUES IMPLEMENTATION

This section lists the selected techniques based on the papers reviewed and chronologically arranged from the early implementation until the latest outcome. This sub-topic will describe the techniques, including techniques implementation, strength, and the algorithm's constraints, a fusion of several techniques implemented for vehicle's stability, a turning ahead, and heading estimation. The authors discrete and discuss the most popular and rarely used technique within USV and AGV in section 3.

2.1. Line of sight guidance

LOS guidance is the missile method used in designing the reference heading and the straight-line direction for the AGV and USV control system. Commonly, the LOS algorithm combines with other practical techniques for generating the new method that enhances vehicle trajectory performance. Qiaomei *et al*. [16] stated that tracking control for the ship using the LOS algorithm could utilize the waypoint guidance algorithm in the simulation. In 2016, Bibuli *et al*. [17] propose integral LOS (ILOS) to increase the robustness concerning external and environmental disturbance. However, the ILOS method will be interrupted by the high lateral gain that causes unstable behaviour. Several studies implement the LOS method in AGV and USV autonomy, such as [18]-[21].

In the same vein, Charajia *et al*. [22] proposed the path following an algorithm that deployed the ILOS method in the underactuated USV in the presence of the environmental disturbance. The simulation of the parameter control design results in accurate stability of the global asymptotic stability (UGAS) as well as of the same local exponential stability (ULES). The ILOS controller can also track the path with disturbance by combining it with other algorithms [23]. The LOS technique had associated and obeyed the COLREGs rule to prevent the avoidance of other civilian vessels and obstacles.

In 2016, Moe and Pattersen [24] suggested LOS guidance to estimate the moving obstacles' trajectory path and ensure that the USV abides by the COLREGs while following the predefined desired path. Furthermore, adaptive LOS (ALOS) is introduced in the control system design to approximate the small-angle linearization. Both the ILOS and ALOS schemes are concentrating on managing the time-invariant sideslip angle. In contrast, Due to external disturbances, or when the AGV and USV tracks a curved path, the sideslip's angle is often time varying.

A guidance law for ALOS is proposed to establish the straight and curve paths via the Fuzzy Logic optimization algorithm. For example, Mu *et al*. [25] introduced a fuzzy logic optimization in the ALOS to optimize the velocity or heading value between the path. Based on the simulation and theoretical analysis, the effectiveness and correctness are shown in the whole path following strategy. Previous studies have combined other LOS guidance methods to achieve the task's requirement in the control system [26]-[32].

2.2. Pure pursuit guidance

Another popular method to update the vehicle position and path commands is PP guidance. This approach is a geometric controller that uses simple and fewer parameters. In 2017, Ameer *et al*. [33] published a paper that describes the geometric controller as suitable for research that eliminates the velocity and acceleration response. However, PP guidance needs to affiliate with other methods to enhance the vehicle's internal force commands. Besides, the deployment of PP guidance is usually found in the AGV

instead of other autonomy [34], [35]. Several autonomies also had implemented PP guidance in the control system for better performance in turning towards the target.

For example, the PP controller computes command in autonomous control design to reach a specific location or to follow in the case of a moving waypoint. The PP controller's trajectory path commanded the AGV and USV to maintain their pose over the waypoint, called dynamic positioning [36]. PP guidance can maintain a vehicle's position on the path in the curvature motion with high speed. This method also tends to chase the target in a short period. In 2008, Breveik *et al.* [37] examined the PP guidance to move toward the target with high speed. Previous studies have also deployed the PP guidance in the control design for curvature and turning path commands [38]-[42]. In the year 2000, PP guidance was implemented in the sizeable AGV and USV control design for estimating vehicle position and generate the steering commands [43].

PP guidance examines the look-ahead distance for designing the virtual path to creating comments in the control system [44]. By computing both positions, the PP guidance controller examines the setpoint and the vehicle's pose. PP guidance contributes to many improvements in the control system to enhance performance and eliminate computational complexity [45]. However, PP guidance in several AGV and USV are implemented because the decency in execution occurred. Implementation of a PID controller with PP guidance has a constraint to optimize and overshoot the parameter. PP guidance usually enhances the AGV's controller's stability despite it founded in the USV implementation [46].

2.3. Constant bearing guidance

In angle estimation and the USV and AGV's velocity is the prevailing method for CB guidance. The deployment of CB guidance in the control design increases the number of researchers to explore the capability of the USV in communication with other autonomy. Breivik and Loberg proposed control design research to improve the underway docking application for USV [47]. In 2015, Agrawal and Dolan demonstrated the deployment of CB guidance in the dynamic environment [48].

This algorithm is crucial to prevent USV collides with a nearby marine vessel, harbour, or coastal region by following the maritime, called COLREGS (rules of the road) [48]. Based on previous studies, Investigating CB guidance is more founded in the underactuated USV instead of actuated USV. In 2015, Norgen implemented a CB guidance scheme for tracking the velocity and angle of AUV and estimate the position of this autonomy [49]. In the same vein, Breivik and Loberg [47] have used CB guidance in the underactuated USV for tracking the waypoint of the mothership.

The control system generates specific motion with the mother vessel based on the command to control the USV movement. CB, LOS, and PP guidance are examples of the missile community whereby the interceptor must adjust the relative interceptor-target velocity along the interceptor-target line of sight [50]. CB guidance is the parallel navigation, which is called a two-point guidance scheme when referring to the USV trajectory aligned with the current waypoint velocity [51]. The distance between USV and the mother vessel followed the virtual target command set based on the motion range.

Some research implements the CB guidance controller for avoiding the obstacles, either static or moving on the path. Bibuli *et al.* [51] stated that USV needs computation highly for matching the motion between the vehicle and the mother vessel because this scenario is known as target hazardous. Hence, the guidance will force USV to follow the new trajectory path, free from the obstacle and safe to manoeuvre towards the next waypoint [52]. Furthermore, CB guidance's target tracking behaviour has like PP guidance to catch the waypoint by matching the velocity with the target [53], [54].

2.4. Lyapunov-based guidance

Recently, in vitro studies have shown that the Lyapunov concept can control the stabilities of the USV by tracking the heading and estimate velocity in cluttered environments. Bai *et al.* [55] found that an input saturation was solved using Lyapunov guidance in designing the path following the controller. commonly, Lyapunov guidance is implemented with another algorithm to solve the problem in the control design. The backstepping method was design based on the Lyapunov concept to increase the stability of USV [55]. Also, Bibuli *et al.* [54] have implemented the Lyapunov concept in the integral of LOS guidance (ILOS) that advances closed-loop kinematic systems.

The slave vessel communicates with the mother vessel by implementing it to decrease an error and avoid the collision. Indeed, the slave vessel can maintain the mother vessel's distance by computes the velocity of the surge, yaw, and sway of the autonomy. The Lyapunov concept's implementation maintains the distance and computes the mother vessel's velocity and heading position either in a linear or curvilinear path. virtual target (VT) implements the Lyapunov concept, where the slave vehicle will aim the VT that was calculated in the control design. Previous research stated that the slave vessel control design is used the Lyapunov concept to generate a reference path to follow a virtual target approach [56].

The fundamental theorem in the Lyapunov established the USV and AGV based on the equilibrium point. However, the control system faced the complexity of decreasing the aberrance of the steering

dynamics occurred. A converse theorem exists in the control system, interrupting the vehicle's balancing mode when USV and AGV equilibrium is stable. Hence, the function generated by the execution is affected due to computational constraints [57]. The Lyapunov controller can stabilize the USV and AGV's nonlinear system besides solving the setting control problem.

2.5. Predictive trajectory planning

Coast guard collision regulation (COLREGs) is the vessel's rule through high water traffic. Predictive Trajectory Planning was introduced in the onboard system to increase USV and AGV guidance. The vehicle's position and the target will be computed and formed the trajectory commands, which comprises collision-free. It will minimize the distance and collision that occurred between the vehicle. This model's structure implemented in the USV and AGV bears the same concept as the target approach [58]. For example, the algorithm was introduced to complies with the COLREGs among civilian vessels and the static obstacle [59]. A five-dimensional trajectory planner based on the lattice was implemented in the water high traffic operation [60].

Similarly, the USV control system implemented lattice-based trajectory planning to reach the moving target. The lattice-based model increases motion safety by guiding USV to follow the trajectory path in high traffic [61]. Besides, Liu *et al*. [62] develop the Kalman filter-based predictive planning model to enhance the performance of estimate the moving ship's trajectories and track the position of onboard USV in real-time. USV dynamics and controlling the action of primitives scales to minimize the search performance on the congestion on the specific region will also be implemented in the planner.

However, the speed of the USV and AGV became lower. It caused the trajectories is slightly offed from the original path when this vehicle is taken different thrusts within the tracking time. The tendency to lose the target is high when the computation program faced the limitation by estimating the target's distance. A range prediction set by the user is lower than the actual [63]. Based on previous research, the implementation of this Predictive Trajectory Planning gives an excellent performance in planning the target's path by combining with other methods [64]-[66].

2.6. Kalman filtering

The name kalman filtering comes from the tasks the method was designed. The USV and AGV need a good navigation system to enhance the performance of guidance. Many researchers utilized an inertial navigation system (INS) and the global navigation satellite system (GNSS) onboard vehicle because of the complementary nature between both electronic principles. Implementation of traditional kalman filtering (KF) able to estimate the position accurately. In 2012, Tran *et al*. [67] examined the KF method's capability in the attitude heading reference system (AHRF). AHRF gave an excellent performance in estimating the roll, pitch, and yaw angles. However, Wang *et al*. found using a traditional Kalman filter, which displays a more massive state error than usual due to the noisy data. Due to this problem, a five-by-one median filter has been added to eliminate the stereo matching error, which interrupted the data [68].

Furthermore, the KF method will cause the cascaded filtering problem due to the GPS data processing used the KF while the other method used in the integration. By employing centralized KF, this problem had been solved [69]. Extended kalman filter (EKF) undergoes the instructions by associating INS and GNSS data fusion. Furthermore, EKF triggers a nonlinear system that develops the commands in advance for creating a new trajectory. Several studies Implementing EKF have been carried out on [70]-[72]. However, the posterior mean and covariance calculation will produce a considerable error value when EKF is included in the computation [73]. The use of EKF still needs improvement for increasing navigation accuracy.

Some errors had been led in tracks the target and within processing the data. The fusion strategy was developed by employing iterated sigma point kalman filter (ISPKF) with interacting multiple model (IMM) to control kinematic and measurement models' changes. This paper concentrates on estimating an aerodynamic parameter and process the trajectory data. In 2015, Lecce *et al*. [74] analyzed the filtered data. The aerodynamic coefficients had been taken to compare with data obtained from the vehicle configuration that used the traditional UKF and ISPKF method. Subsequently, ISPKF ready to improve the precision and the vigour of the UKF. However, the implementation of the UKF still faced a constraint in eliminating the gaussian distribution.

2.7. Backstepping method

The backstepping method comprises an algorithm employed in many USV and AGV due to the capability to track and follow the setpoint based on the commands onboard had set up. Several studies give attention to this method for developing the under-actuated vessel [75]. Persistent exciting (PE) is an example of the backstepping-based model implemented on the USV and AGV to control the under-actuated USV and

AGV. In-depth, PE potentially drives USV and AGVs on arbitrary trajectories, including circle, straight-line, and curved trajectories.

In 2011, Ma *et al*. [75] introduced the new straight-line path-following control algorithm for improving path following control performance. Combining two methods: yaw angle feedback and backstepping technique in the control design increases the closed-loop stability-besides, the straight-line path following algorithm shown the feasibility and validity in the simulation results. Furthermore, an adaptive dynamical sliding mode is an example of backstepping implementation to validate the performance of underactuated USV follows the trajectories [76]. In the same vein, Chen *et al*. [77] proposed research to control the movement and follow the trajectories based on the Backstepping method assisted with the adaptive mode control theory. The result has shown good performance in tracking the nonlinear USV and AGV control system.

In 2018, Deng *et al*. [78] designed a fusion of three techniques, Lyapunov, backstepping, and genetic algorithm (GA), for creating a right angle and speed tracking. Lyapunov-based stability theory increases the global asymptotic stability and maintains the USV and AGV heading to follow the trajectories. In 2017, Liu *et al*. [79] implemented sliding mode integration and dynamic neural method internally high-precision and fast navigation response that consist of the internal backstepping control loop to enhance the control system performance. Many researchers have also implemented the neural mode model to realize the USV and AGV's accurate and stable tracking in the steering process [80].

2.8. Motion goal prediction

Motion goal prediction is reckoned as a real-time planner when this algorithm computes the commands directly onto the onboard system to generate the trajectories. Three elementary processes will consult the algorithm's ultimate output, including the USV and AGV desired pose, the vehicle's velocity, and arrival time. The low-level controller executes the commands neatly, maintains the position on the track, and receives the target within the time. Hence, this algorithm can guide the USV and AGV in cluttered surroundings by controlling its onboard action. In 2014, Svec *et al*. [81] overcame the USV operation in the cluttered environment by implementing the motion goal prediction algorithm. The planner computed the distance between two vehicles and complies with the guiding commands to maintain the USV and AGV on the trajectories. This algorithm had designed for an un-predefined position because the vehicle might not have earlier data about the objective vessel's proposed movement.

3.   RESULTS AND DISCUSSION

Table 2 lists the capabilities and advantages of the techniques used in the AGV and USV control systems. Among all the studies reviewed so far, stability control is the most critical for USV and AGV studies. Hence, the fusion of techniques is crucial in the USV and AGV to create the best control design. This is because the USV and AGV need many capabilities to move to achieve the task requirement by including all the aspects, especially the tracking performance. The fusion of LOS and the fuzzy logic method significantly impacts the vehicle stability for three significant controls; straight line, curve, and heading modification. Employment of the backstepping method with another technique creates a new AGV and USV control system that is more stable in terms of DOF control, state estimation of the path, and collision avoidance. However, a fusion of computation techniques will reduce the system's efficiency and generalize the commands quickly.

Several techniques implemented in the control system design were selected and analyzed based on the method's ability to perform the task. Based on the observation, most control system techniques are designed to manipulate the speed, heading position between the USV and AGV, and the target path. The LOS, CB, and PP guidance are the most suitable suggestions for reducing the tendency to lose the target. LOS, CB, and PP controllers' implementation usually enhance the performance of the USV and AGV motion topic. Previous research shows that the LOS controller is the most popular technique to control the DOF dynamic (sway, surge, and yaw) rate. Many researchers implemented the LOS controller in their experiment to control the DOF and follow the trajectory path because this controller is easily implemented on the USV. Several techniques were also associated with the LOS controller to set off the hydrodynamic state on the water surface during the following process. The effectiveness of controlling AGV and USV in the time-parameterized by the heading reference and the waypoint design will increase the LOS controller's employment.

PP guidance is a famous method in the AGV guidance performance of stability, turning ahead, and heading estimation. However, this controller is practised only in a few studies for the USV, such as done in [82], [83]. Next, the performance of AGV and USV for tracking the position will be promptly increased by using a fusion of Kalman filtering to generate the heading and eliminate the system's noise disturbance. Furthermore, motion goal prediction, Lyapunov, and the predictive planning model were implemented in the

computation control system to enhance the vehicles' DOF's stability and increase the jumbled condition's robustness, such as high traffic the water surface. LOS, PP, and CB controller is known as the missile technique, which is technically designed for chasing the target during the duration set.

Table 2. The analysis of AGV and USV techniques

Techniques	LOS	PP	CB	Lyapunov	Predictive Trajectory	KF	Backstepping	Motion Goal
Stability Control								
Straight-Line Path	ST	TT	TT	TT	-	TTT	TT	TT
Curve Path	ST	TT	TT	TT	-	TTT	-	-
Heading Modification	TTT	TT	TT		TT	TTT	-	-
Sideslip Angle	ST	-	-	TT	-	-	-	-
DOF Control								
Yaw	ST	ST	ST	TT	-	TTT	ST	ST
Sway	ST	ST	ST	-	-	TTT	ST	ST
Surge	ST	ST	ST	-	TT	TTT	ST	ST
State Estimation								
Predefined Path	ST	TT	TT	ST	-	-	ST	-
Unknown Position	-	TT	-	-	-	ST	-	TT
Collision Avoidance								
Static Obstacle	ST	TTT	-	-	TT	-	-	-
Moving Obstacle	ST	TTT	-	ST	TT	TT	ST	-
Motion Control								
Constant	-	-	TT	-	TT	-	-	-
Variation of Motion	TT	-	TT	-	TT	ST	-	TT
Vehicle Actuation								
Under Actuation	ST	TT	ST	ST	ST	ST	ST	ST
Fully Actuation	-	-	-	TT	-	-	-	-

Note: ST for Standard Technique, TT for a fusion of Two Technique, TTT for fusion more Than Two Technique

4. CONCLUSION

In conclusion, this paper had reviewed more than 50 papers of literature from the last ten years about the techniques in AGV and USV developments. Path following and trajectory tracking techniques were emphasized in this paper to identify and validate each technique's functionalities for AGV and USV performance. The deployment of the technique was customized based on the requirement and the risk of the mission. LOS guidance was suggested in many research for tracking the heading angle and velocity of the target, which will guide the AGV and USV towards the position. Based on the analysis given, the fusion of Kalman filtering is the prevalent method for navigation purposes. It gives a good performance in the state estimation in the underactuated AGV and USV. The technique which was performed in the simulation test needs further research that will expose the actual situation. The motion goal prediction method is proposed to track the un-predefined target by designing the algorithm that concerns the desired heading angle and velocity parameter.

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BIOGRAPHIES OF AUTHORS

Putri Nur Farhanah Mohd Shamsuddin received her Bachelor of Engineering Technology (Electrical) degree with honor, Universiti Malaysia Pahang. She is currently further her studies in Master of Engineering Technology at Universiti Malaysia Pahang. Her research interests include the navigation system and its applications.

Roshahliza M. Ramli received her Bachelor of Engineering degree in the information system, the Master of Engineering degree in electrical engineering and computer science from the Polytechnic University of Japan, in 2010 and 2008, respectively, and the Ph.D. degree in electrical, electronic and system engineering (Signal Processing) from Universiti Kebangsaan Malaysia, in 2015. She is currently a Senior Lecturer at the Faculty of Electrical and Electronics Engineering Technology, University Malaysia Pahang. Her research interests include telecommunication technologies, digital/adaptive filtering, speech/audio processing, system and algorithm development, and their applications.

Muhamad Arifpin Bin Mansor received his Bachelor of Engineering (Electronic Engineering) at Oita University, Japan, in 1990, the Master of Engineering (Electric, Electronic, and Computer Engineering) at Kyushu Institute of Technology, in 1997, and the Doctor of Engineering (Information Science and Control Engineering), Nagaoka University of Technology, Japan, in 2010. He is currently an Associate Professor at the Faculty of Manufacturing and Mechatronic Engineering Technology, College of Engineering Technology, Universiti Malaysia Pahang, Malaysia. His research interests include Internet technology, Computer Network, Operational Research, Total Productive Maintenance, Performance Measurement, and Open Source.